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Electrifying Engagement in Middle School Science Class: Improving Student Interest Through E-textiles

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Abstract Most interventions with "maker" technologies take place outside of school or out of core area classrooms. However, intervening in schools holds potential for reaching much larger numbers of students and the opportunity to shift instructional dynamics in classrooms. This paper shares one such intervention where electronic textiles (sewable circuits) were introduced into eighth grade science classes with the intent of exploring possible gains in student learning and motivation, particularly for underrepresented minorities. Using a quasi-experimental design, four classes engaged in a traditional circuitry unit while the other four classes undertook a new e-textile unit. Overall, students in both groups demonstrated significant learning gains on standard test items without significant differences between conditions. Significant differences appeared between groups' attitudes toward science after the units in ways that show increasing interest in science by students in the e-textile unit. In particular, they reported positive identity shifts pertaining to their perceptions of the beliefs of their friends, family, and teacher. Findings and prior research suggest that student-created e-textile designs provide opportunities for connections outside of the classroom with friends and family and may shift students' perceptions of their teacher's beliefs about them more positively.

Keywords Science education · Electronic textiles · Maker movement · DIY media · Perception of science · Interest

Introduction

The U.S. Department of Commerce projects science, technology, engineering, and mathematics (STEM)-related employment will increase 7% more than other sectors by 2018, with technology acting as the major economic driver (Bureau of Labor Statistics 2013; Langdon et al. 2011). Currently, only 16% of U.S. undergraduates choose a natural science or engineering major (National Science Board [NSB] 2010), reflecting both a lack of preparation and interest in STEM fields (PCAST 2010; Tai et al. 2006). Further, women (29% of STEM workforce) and historically underrepresented racial and ethnic minorities (11% of STEM workforce) are substantially underrepresented across STEM disciplines (NSB 2016). According to the Congressional Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development (2000), diversifying the pipeline of prospective STEM workers would both permit labor supply to meet projected demand and engage a greater diversity of perspectives that could increase the rate of innovation.

In addition to a "participation gap" in STEM fields, many individuals from groups underrepresented in STEM fields experience an "identity gap," where they struggle to see themselves

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as STEM professionals (Tan et al. 2013). The middle and high school years are when students are mostly likely to lose interest in science (George 2006; Miller et al. 2006), and it is highly unlikely that these students will return to engage in STEM-related fields later in life (Jack and Lin 2014). Thus, it seems necessary to increase both STEM interest and preparation using strategies that facilitate a more diverse group of students envisioning themselves as prospective STEM professionals in middle and high schools if we are to meet the economic demands for a trained workforce capable of driving innovation.

Participating in inquiry-based, hands-on science learning activities is an approach that holds significant promise for increasing middle school students' interest in pursuing science and engineering as their careers (Gibson and Chase 2002; Kong et al. 2014). One promising avenue for providing such learning opportunities in the classroom builds on the momentum of the Maker Movement. Though the Maker Movement began with garage-based hobbyists across the U.S.A., the lower cost of hardware, open-access software, and rapid protoyping technologies have facilitated its spread across a variety of venues, including community and library spaces (Sheridan et al. 2014). In 2014, President Obama launched his "Nation of Makers" initiative, including a "Week of Making" and the annual White House Maker Faire. One of the central goals of a Nation of Makers is to provide school-aged youth with access to the kinds of hands-on, interest-driven activities promoted by the Maker Movement and the rich STEM learning experiences such activities embody (Halverson and Sheridan 2014; Vossoughi and Bevan 2014). However, as Dougherty (2013, p. 8) has argued:

> The biggest challenge and the biggest opportunity for the Maker Movement is to transform education…. Increasingly, technology has given students more control over their lives, and even the simplest cellphone can change a person's sense of agency. Students are seeking to direct their own education lives, looking to engage in creative and stimulating experiences. Many understand the difference between the pain of education and the pleasure of real learning. Unfortunately, they are forced to seek opportunities outside of school to express themselves and to demonstrate what they can do.
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> Formal education has become such a serious business, defined as success at abstract thinking and high-stakes testing, that there is no time and no context for play. If play is what students do outside school, then that is where the real learning will take place and that is where innovation and creativity will be found.

Indeed, as Dougherty elucidates, the Maker Movement holds substantial promise for transforming educational experiences, but doing so also requires some reconciliation of the hands-on, interest-driven nature of the Maker Movement with the educational frameworks by which students and teachers are measured, namely standards-based testing. Widespread adoption of new teaching technologies is unlikely to occur in schools without evidence of improved learning and interest outcomes in direct comparison to those currently being employed in classrooms. Thus, more research is needed to define, standardize, and examine the learning and interest outcomes of making activities within K–12 settings before schools can potentially adopt widespread curricular changes (Blikstein and Krannich 2013; Halverson and Sheridan 2014).

The current study addresses this need. Using a quasi-experimental design, we directly compare motivation, identity, and learning outcomes associated with making and non-making approaches to the study of electricity in eighth grade classrooms. The making-based instruction employed the use of electronic textiles (e-textiles), in which electronic components such as LED lights, batteries, and microcontrollers are sewn together using conductive thread and then programmed. In this way, e-textiles incorporate elements of embedded computing and circuit design into a craft-based project approach. Classes that received non-making instruction covered equivalent content but utilized traditional materials, such as bread boards and alligator clips to develop prespecified circuits. To our knowledge, this is the first controlled study to assess student outcomes associated with the inclusion of e-textiles in science classrooms.

Background

Interest and Engagement in STEM

One key aspect of supporting learning in science is to engage students' interests. Student interest plays a crucial role in predicting students' persistence at learning (Hidi 1990). Interest not only influences academic achievement (Schiefele et al. 1992) but also strongly predicts choice of major in post-secondary education (Beggs et al. 2008; Tai et al. 2006; Tan and Laswad 2009). Without prior exposure and interest, students remain unlikely to choose a particular area as their choice of major (Hall et al. 2011; Tobias 1994).

One documented way to support student interest is through inquiry-based classroom practices (Abd-El-Khalick et al. 2004; Ford 2008; Sneider 2012). Inquiry and design-based learning provide models for fostering students' science interest by engaging students in projects to understand the value and relevance of engineering design and scientific thinking, processes, and experimentation in their everyday lives (Costa 1995; Dorph and Cannady 2014). If science content and practice can be embedded in the context of students' everyday life experiences (including prior interests and knowledge), this may support new development of interest in science (e.g., Martin and Dixon 2013; Norris 2014; Petrich et al. 2013). Conversely, when students do not connect or identify with science learning, they often retain negative feelings toward science (Basu and Barton 2007).

E-textiles have shown evidence of expanding students' views of and interests in computing through the intentional hybridity of crafting, computing, and circuitry. Kafai et al. (2014b) identified three main aspects of e-textiles that promoted students' interests in computing. First, as alluded to earlier, e-textiles provide *transparency* into computing and electricity, allowing students to see connections laid out clearly and to see the connections between written code and actual effects. Second, e-textiles are *tangible*. The physicality of projects allows them to travel, creating opportunities for students to show their projects to friends, family, teachers, and community members, creating an audience for science and computing. These promote identity moments as students not just show off interesting light-up garments but explain how they work. Third, the particular pedagogical approach used with many e-textile interventions (including that described in this paper) promotes creativity within constraints (Stokes 2008). While all students work on the same project, with requirements that support common learning goals, these projects are open-ended. Practically, this means that students feel like they can create whatever they want: hats, stuffed animals, hoodies, backpacks, and so on. This supports *personal autonomy* within a rigorous learning environment.

For example, students are able to pursue personalized aims within the context of classwork when they engage and overcome challenging problems that require deep content understanding in pursuit of their own visions for the aesthetics of their projects. Thus, the design decisions driven by the personal aesthetics of a project are intricately inter-related with the science, computing, and engineering involved in that project. These are not projects where art and aesthetics are extrinsic to the core disciplinary learning involved. Rather, the crafting, circuitry, and coding are inseparably related, making personalized projects a source of both learning and interest (Kafai et al. 2014a).

Maker activities provide potentially motivating opportunities to build interest in science by supplying a personally relevant context through interest-driven student-centered projects with hands-on materials and digital fabrication technologies (Blikstein 2013). E-textile projects in particular can provide students with a great deal of autonomy in making design decisions (aesthetic and/or functional), creating opportunities for them to construct objects of personal value (e.g., Kafai et al. 2014a) while tackling meaningful problems (Blikstein 2008). Not only are they design activities that lend themselves to connecting personal interests with science and engineering practices, they provide an alternative to the machine-driven fabrication technologies that start on the screen before making it into students' hands. In contrast, e-textiles integrate handcrafts and cultural funds of knowledge not often valued in schools (Gonzalez et al. 2005; Moll et al. 1992; Sleeter and Grant 1991). This has shown some promise in bringing non-dominant groups to STEM, including women and girls (Searle et al. 2016; Weibert et al. 2014), urban students (Kafai et al. (2014b), and American Indian students (Searle & Kafai 2015b).

Engaging multiple levels of meaning that resonate with personal, familial, and cultural values and identities may better support the sustained development of interest in STEM (Aschbacher et al. 2010; Harackiewicz et al. 2012; Navarro et al. 2007; Tang et al. 1999; Turner et al. 2004). Many students with demographic profiles underrepresented in STEM fields report having a difficult time envisioning themselves as scientists or engineers based on established stereotypes of who does—and who does not—fit in as a member of those professions (Archer et al. 2012; Calabrese Barton et al. 2013). Even students who may enjoy and demonstrate high achievement and confidence in science classes do not necessarily experience the discipline as something compatible with their identity (Archer et al. 2010). Consequently, they do not consider STEM careers to be viable or interesting to them. However, students who grow up in households where interest in science is present report earlier serious interest in STEM topics and are more likely to pursue STEM careers (Dabney et al. 2012). Further, students enrolled in STEM classes and programs cite familial encouragement for their STEM pursuits as a major influence in their motivation to improve their academic performance in science (Hidi and Harackiewicz 2000) and make subsequent science-related career choices (Sjaastad 2012).

Thus, familial support and enthusiasm for STEM-related activities—especially those that occur as part of formal science classes—may be crucial for influencing students' assessment of identity compatibility and motivation to pursue science over the long term. For example, Aschbacher et al. (2010) reported that students "were buoyed by perceived strong and aligned support for their science identities at home, at school, and in extracurricular activities" (p. 15). Conversely, in a different study, many children who reported low levels of home support for science consistently reported lower levels of STEM interest (DeWitt et al. 2013).

Learning About Electricity and Circuitry

Many studies (e.g., Baser 2006; Chang et al. 1998; Engelhardt and Beichner 2004; Liégeois and Mullet 2002; Pesman and Eryilmaz 2010) document the challenges of teaching students about electricity and circuits due to common misconceptions. Some of the areas in which students face particular challenges include current flow (e.g., Osborne 1981; Sencar and Eryilmaz 2004), polarity (e.g., Osborne et al. 1991), parallel circuits (e.g., Chambers and Andre 1997), circuit connections (e.g., Osborne 1983), and short circuits (e.g., Fredette and Clement 1981). Efforts to avoid the development of such misconceptions have included both inquiry-based approaches using traditional materials such as batteries, wires, and light bulbs (e.g., Osborne 1983) and through causality-focused discussions that accompany hands-on circuit construction (e.g., Perkins and Grotzer 2005).

E-textiles provide a unique way for students to encounter and think through issues with electricity and circuitry that incorporate and expand upon previous inquiry approaches. For instance, Peppler and Glosson (2013) engaged children in a Boys and Girls Club in a series of lessons and projects with circuits, pairing limited instructional presentations with projects dealing with simple, parallel, and computational circuits. Following the sequence of projects, they tested students' understanding of simple circuits through an original assessment where students drew circuits with familiar components used in their projects (i.e., sewable LEDs, switches, and a battery). They found that students significantly improved their understandings of current flow, polarity, and electrical connections while also improving their ability to diagram a working circuit.

The unique affordances of e-textile materials may facilitate such learning. Kafai et al. (2014a, 2014b; Searle et al. 2016) argue that students' use of uninsulated thread that is continuous rather than alligator clips which are provided with insulation in a predetermined length facilitates more varied encounters with common conceptual challenges involving current flow and short circuits. While many students begin by sewing lights as if they were buttons, continuing the thread through both polarized sides of the LEDs, they quickly discover the need to cut the thread to direct the electricity through a desired component to avoid a short circuit. This principle often eludes students when using alligator clips since the alligator clips already have two ends and no cutting is necessary. Similarly, loose threads on the back of a project will often cause a short circuit when they cross the positive and negative lines. This too is an error that would rarely occur using alligator clips because the insulation generally prevents touching wires from causing a short circuit. In addition, creating connections becomes a very conscious act that entails practical applications of fundamental principles of conductivity and resistance—especially related to the thickness of the connection between the conductive thread and a component. Students must learn to sew each electrical component thoroughly ("three times through" is a common phrase) to ensure that circuits stay closed after stitching and that connections of insufficient thickness do not impose excessive resistance which would impede necessary current. Often, new creators do not think to do this and have LEDs and snaps hanging loosely off their projects. They soon discover that these work only when the circuits are held just right due to loose connections, and they have to go back and re-sew them more thoroughly, leading to very solid remembering of what makes a functional electrical connection versus a simple physical attachment.

Research Questions

The above sections provide some background about what students can learn with e-textiles and how e-textiles can promote interest in computing and science. However, most of the available evidence derives from design-based research and case studies, which do not provide the basis for comparative advantages in student outcomes. Further, little scholarship explores e-textiles in classrooms, especially in non-elective classes taught by a practicing classroom teacher. Further, there is a paucity of research documenting to what extent making with e-textiles can promote students' learning outcomes regarding electricity and circuitry compared to a traditional instructional approach. It remains unclear whether students' interest and identities established during e-textile making may potentially promote their interest in science learning within a formal context. Thus, the current study examines the impacts of e-textile making when integrated into a standards-based, eighth grade science curriculum with the expectation of enhancing school-based achievement. With this in mind, we explored the following research questions:

1. Is implementation of an e-textile unit in a middle school science curriculum associated with greater student motivation, interest, and value for STEM content and careers compared to a traditionally formatted unit covering electricity and circuits?
2. Is implementation of an e-textile unit in a middle school science curriculum associated with better student learning outcomes than a traditionally formatted unit covering electricity and circuits?

Participants receiving the e-textile instruction were hypothesized to demonstrate significantly greater gains on all measures than those in the control condition.

Method

Using established e-textile projects (Tofel-Grehl and Fields 2015; Howell et al. 2016) and a quasi-experimental research design, we examined student motivational and learning outcomes, as well as changes in student attitudes toward science and their interest in future careers in science as a function of assigned instructional condition.

Setting and Participants

Site Mountain High Middle School (MHMS; pseudonym) is a rurally located middle school in the Mountain West region of the U.S.A. An economically diverse school with 20% of students on free and reduced lunch program assistance, the school serves a town with a population of approximately 10,000 people. This diversity comes in a bimodal income distribution with students who come from highly affluent or more transient and low-income home situations. Of the approximately 550 students enrolled, the school reports 70% of students to be Caucasian, 26% to be Latino, and 4% to be of other ethnic backgrounds. Approximately 78% of students score in the proficient or above range in both their mathematics and reading standardized test scores.

Students Student participants for the study were in the eighth grade of the participating school. All eight sections of MHMS's eighth grade science classes participated in the study, with four receiving an e-textile unit and the remaining four receiving instruction from the teacher's conventional curriculum unit on electricity and circuits.[1] The full population of 155 students consented to participate in the study.

Teacher The teacher who participated in the development and deployment of the e-textile unit was the science teacher for all eight sections. With 10 years of classroom experience, Mr. Soto (a pseudonym) is currently working toward his national board certification. In Summer 2013, he participated in a professional development opportunity offered by his district focusing on design and the Maker Movement. After designing his own e-textile project in the professional development workshop, Mr. Soto was highly motivated to do similar activities with his students during their annual unit on electricity. He sought out the research team to help him incorporate some of the e-textile projects from his professional development learning into his classroom practice. Upon meeting with additional members of the research team, both the teacher and the district voiced their willingness to allow for a quasi-experimental deployment of a newly developed e-textile curriculum.

Unit Design

The electricity unit was developed by the lead science teacher at MHMS with assistance from the members of the research team. Unit and lesson development was a collaborative and iterative process between the researchers and the classroom teacher. The teacher's expertise and knowledge of the state standards as well as his training in *Project Lead the Way* (Katehi et al. 2009) informed the content and sequencing of the content lessons (Howell et al. 2016).

Because the research design for this study was quasi-experimental, the control and treatment curricular units were designed with content equivalence in mind. As much as possible, the units mapped onto each other with regard to instructional time, standards-driven content, and independent student work time. In order to ensure instructional equivalence surrounding the target content, the control and treatment (e-textiles) units were designed to be identical in instructional method until the deployment of specialized projects. Ten discrete content lessons were developed for each condition. These ten lessons took approximately 5 h of direct instructional time and were comparable across treatment and control groups (see Table 1). These lessons met the eighth grade learning standards required by the district and state where MHMS is located.

Both control and treatment groups were provided approximately 20 h of in-class work time to accomplish three content-aligned projects, resulting in 25 h of dedicated classroom time per condition (see Table 2). Projects across treatment and control units were selected to provide equivalent work time and content engagement. Students from both the control and treatment groups were allowed to bring projects home with them for further exploration.

Data and Analysis

Data and analysis for this study focused on three areas: surveys of students' science identity beliefs and motivation,

Table 1 Shared lessons for the treatment and control classes

Shared unit lessons
1—Introducing electricity and electron transfer
2—Introducing circuits and circuitry
3—Conductivity and simple circuits
4—Types of circuits
5—Measuring voltage
6—Batteries
7—Ohm's law
8—DC motor
9—Electro magnets
10—Short circuits

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[1] Eighth grade science at MHMS is taught by two teachers responsible for four sections each. One teacher has stronger content expertise in physical sciences and the other has stronger content expertise in life sciences. As a standard practice to maximize their collective impact, the teachers switch sections midway through the Spring term to cover units dedicated to their respective areas of strength. Thus, the same teacher taught all eight sections for the electricity unit. Two sections primarily assigned to each teacher were selected arbitrarily and assigned to the treatment condition, and the remaining two from each teacher were assigned to the control condition.

Table 2 Project lessons for control and treatment groups

Control	Treatment (e-textiles)
Drawing circuits	Paper circuit
Creating circuits with breadboards	Bracelet with switch
Identifying and debugging short circuits	Pre-programmed circuit

observation and interviews concerning student engagement and teacher instructional practices, and assessment of learning.

Students' Science Identity Beliefs and Motivation Students were given an abbreviated version of the *Is Science Me* (ISM; Gilmartin et al. 2006) survey. *ISM* provides students with a wide range of questions that attempt to capture both their feelings toward STEM disciplines and careers as well as their perceptions of the beliefs of their families and peers.

Mann-Whitney *U* tests were used to determine differences between control and treatment groups, because the questionnaire items employed ordinal Likert scales with an insufficient range (four-point scale) to assume interval properties. Examination of the pretest data found no significant differences between groups, so post-only comparisons were conducted. Consistent with the hypotheses, one-tailed Mann-Whitney *U* tests were conducted to determine the difference between control and treatment groups for posttest conditions concerning teacher, family, and peers.

Student Engagement and Teacher Instructional Beliefs: Members of the research team observed and videorecorded the teaching of all eight sections of the control and treatment groups. Observations focused on the instructional practices engaged in by the teacher, the discourse practices of the students both with their teacher and with their peers, and the classroom dynamics observed during activity and project work times. In addition, ethnographic interviews (Spradley 1979) were conducted with the teacher and some students that focused on decision-making processes relevant to the unit projects in each condition. These data were analyzed for holistic patterns and themes targeting instructional practices and classroom discourse. A content analysis of field notes focused on isolating trends in the interactions between the teacher and the students across control and treatment groups.

Learning Assessment All students in each condition completed pre- and posttests on both the electricity and circuitry content. Five multiple-choice items assessing knowledge of electricity and circuits appropriate to the curricula delivered in both the control and treatment conditions were gleaned from the eighth grade science tests used in the Third International Mathematics and Science Study (TIMSS 2011) and the National Assessment of Educational Progress (NAEP 2014).

Analyses of covariance (ANCOVA) and paired *t* tests were used to analyze students' responses on the multiple-choice learning assessment. To assess differences in learning outcomes between conditions, the ANCOVA model used pretest scores as a covariate, dummy coding for treatment condition as the independent variable (1 = treatment; 0 = control), and posttest scores as the dependent variable for each item. Paired *t* tests were used to assess learning gains within conditions.

Results

To best address the research questions, the results of the analyses described in the preceding section are presented in three sections in the following paragraphs: *student identity beliefs and motivation*, *student engagement and classroom instructional practices*, and *learning outcomes*. The first and third sections report the findings of statistical analyses assessing changes from pretest to posttest. The second section reports the qualitative findings drawn from classroom observations and individual interviews with the teacher and a diverse subsample of students.

Students' Science Identity Beliefs and Motivation

The descriptive statistics revealed a general trend supporting stronger positive perceptions of science amongst the students in the treatment (e-textiles) than those in the control condition, with effect sizes in the small-to-medium range (Cohen 1988) (see Table 3). Analysis of pretest results showed equivalency of treatment and control groups; thus, analysis focused on posttest differences only. *ISM* items related to social relationships showed statistically significant differences favoring e-textile students on the Mann-Whitney *U* test for posttest results. Because the questionnaire was coded from 1 (agree strongly) to 4 (disagree strongly), lower mean ranks reflect stronger aggregate positive responses (i.e., lower numbers show stronger positive perceptions of science). The treatment group had lower mean ranks than the control group on all items related to teachers, family members, and peers, respectively.

Item Responses Related to Teacher The results uncovered significant between-group differences for two variables regarding participants' perception of teacher support in their science learning (see Table 3):

- "My teacher cares if I think science is interesting." ($U = 2438.00$, $z = -2.17$, $p = 0.015$)
- "My teacher cares if I learn science." ($U = 2471.50$, $z = -2.108$, $p = 0.018$)

For the first question, the treatment group has a lower mean rank of 70.76 in contrast to the control group's mean rank of 85.34, yielding an effect size of $r = 0.17$ (small–medium; Cohen 1988). Similarly, in the latter question, the treatment

Table 3 Posttest mean ranks and significant results of Mann-Whitney U tests on teacher, family, and peer effects (one-tailed)

Questionnaire item	Experimental condition	Mean rank	N	U	z	p	r
Teacher							
My teacher cares if I think science is interesting.	T ($n = 78$)	70.76	155	2439.00	−2.17	0.015	0.17
	C ($n = 77$)	85.34					
My teacher cares if I learn science.	T ($n = 78$)	71.19	155	2471.50	−2.11	0.018	0.17
	C ($n = 77$)	84.90					
Family							
It is important to my family that I try my best in school.	T ($n = 78$)	74.02	155	2692.50	−2.00	0.023	0.16
	C ($n = 77$)	82.03					
My family would be happy if I chose to pursue a career in science, technology, or engineering.	T ($n = 77$)	66.49	154	2117.00	−3.31	0.001	0.27
	C ($n = 77$)	88.51					
Peer							
How many of your close friends: like science, technology, or engineering?	T ($n = 77$)	71.56	154	2507.50	−1.77	0.039	0.14
	C ($n = 77$)	83.44					
How many of your close friends: think science, technology, or engineering is cool?	T ($n = 77$)	72.65	154	2591.00	−1.44	0.075	0.12
	C ($n = 77$)	82.35					
How many of your close friends: get good grades in science, technology, or engineering courses?	T ($n = 77$)	74.27	153	2716.00	−.84	0.202	0.07
	C ($n = 76$)	79.76					
How many of your close friends: care about your grades in school?	T ($n = 77$)	68.58	154	2277.50	−2.60	0.005	0.21
	C ($n = 77$)	86.42					
How many of your close friends: encourage you to do well in class?	T ($n = 77$)	69.73	154	2336.00	−2.25	0.012	0.18
	C ($n = 77$)	85.27					

group has a mean rank of 71.19, and the control group has a mean rank of 84.90, yielding an effect size of $r = 0.17$ (small–medium; Cohen 1988).

Item Responses Related to Family Two questions in the questionnaire designed to measure perceptions of familial support were statistically significant as a function of experimental conditions:

- "It is important for my family that I try my best in school." ($U = 2692.50$, $z = -2.00$, $p = 0.023$)
- "My family would be happy if I chose to pursue a career in science, technology, or engineering." ($U = 2117.00$, $z = -3.31$, $p = 0.001$)

For the first question, the treatment group has a lower mean rank of 74.02 in contrast to the control group's mean rank of 82.03, yielding an effect size of $r = 0.16$ (small–medium; Cohen 1988). The latter question sees a wider discrepancy between the two groups in their mean ranks, with a mean rank of 66.49 for the treatment group and 88.51 for the control group, yielding an effect size of $r = 0.27$ (medium; Cohen 1988).

Item Responses Related to Peers Three variables measuring peer effects were significant. They were:

- "How many of your close friends: Like science, technology or engineering." ($U = 2507.50$, $z = -1.77$, $p = 0.039$)
- "How many of your close friends: Care about your grades in school." ($U = 2277.50$, $z = -2.60$, $p = 0.005$)
- "How many of your close friends: Encourage you to do well in class." ($U = 2336.00$, $z = -2.25$, $p = 0.012$)

For the first question, the treatment group has a lower mean rank of 71.56 in contrast to the control group's mean rank of 83.44, yielding an effect size of $r = 0.14$ (small; Cohen 1988). Similarly, the treatment group has a mean rank of 72.65 in the second question, and the control group has a mean rank of 82.35, yielding an effect size of $r = 0.21$ (small–medium; Cohen 1988). For the third question, the treatment group mean rank is 68.58 and the control group mean rank is 86.42, yielding an effect size of $r = 0.18$ (small–medium; Cohen 1988).

Student Engagement and Teacher Instructional Practices

Overall, our observations and the teacher's reflections provide limited context for why students in the e-textile classes may have developed changed perceptions of their family's and friends' regard for their participation in science. Students in the e-textile groups reported more instances of bringing their projects home with them to work on over the weekends. As one student said, "my mom will love this stuff!" This may have increased parental awareness of child science learning in the e-textile group. When queried about this phenomenon, students in the e-textile classes expressed enthusiasm about sharing this work with their families because they believed their families would be excited to see their e-textile creations, such as sewn representations of flags from parents' countries of origin. Conversely, control group students were neither reported nor observed doing this; students in the control groups declined proffered opportunities to bring their projects home with them. No similar shift in perceived parental enthusiasm was articulated by the students in the control classes. When directly asked about what their parents thought of their science work, a student in the control group responded "So long as I am not in trouble, Mom and Dad won't care." The perception from students appeared to be that school work did not translate to their home lives.

Another possible explanation of an increased student perception of parental value would be a connection with the home or personal values and skills of the students' families. Several students in the e-textile groups asked to bring their projects home because they had a family member who worked professionally as a seamstress or tailor. In this way, e-textile activities may have provided entry into science education for families who otherwise did not find it accessible. Similarly, students used the opportunity to work in e-textiles to create artifacts reflecting themes of importance to members of their families (e.g., national flags). Mr. Soto noted in an interview that several students who had previously shown little to no interest in science suddenly engaged more with the e-textile projects. Some students in the e-textile classrooms took their projects home and did homework (i.e., finished their projects) for the first time that school year during the e-textile unit. As the teacher noted:

> Take a room of twenty-five middle school students and put a needle and thread in their hand, and the only sound you will hear is that of utter concentration. I can't explain it, but during this sewing time my students had higher levels of concentration and focus than many of the other hands-on activities in my classroom.

Mr. Soto's observations about student engagement might also speak to the differences found in the *ISM* inventory regarding family interest and valuing of STEM. It is possible that student interest was increased because of the novelty of the activities, and thus, parents became more engaged and invested in that aspect of their children's education. There is also the possibility that the teacher engaged differently with the two different sets of classes because of the materials and ways in which those materials afforded him different opportunities. Field note observations indicate that the periods of time spent in discussion, both as a large group and with individual students, appeared greater with the e-textile sections rather than the traditionally taught classes. These discussions and opportunities to engage in talk around their work may also be responsible for improving student interest.

Learning Assessment

Performance on the five-item multiple-choice content assessment revealed trends of learning in both treatment and control conditions. Paired t tests using binary data on test scores (0 = incorrect; 1 = correct) indicated that students in each condition demonstrated significant gains in several areas when comparing pretest and posttest (see Table 4). Comparison of item-by-item gains within conditions yielded two items with significant gains in the control condition (item 1: $M_{\text{diff}} = -0.222$, SD = 0.610, $t = -3.090$, $p = 0.003$, $r = 0.222$; item 2: $M_{\text{diff}} = -0.091$, SD = 0.370, $t = -2.325$, $p = 0.022$, $r = 0.156$) and three items with significant gains in the treatment condition (item 1: $M_{\text{diff}} = -0.159$, SD = 0.609, $t = -2.173$, $p = 0.033$, $r = 0.159$; item 2: $M_{\text{diff}} = -0.0925$, SD = 0.289, $t = -2.949$, $p = 0.004$, $r = 0.182$; item 4: $M_{\text{diff}} = -0.0526$, SD = 0.225, $t = -2.041$, $p = 0.045$, $r = 0.164$). Effect sizes for significant items were small–medium ($0.156 \le r \le 0.222$; Cohen 1988). Gains on a fourth item in the treatment condition approached significance with a small effect (item 5: $M_{\text{diff}} = -0.0800$, SD = 0.359, $t = -1.932$, $p = 0.057$, $r = 0.091$). However, an analysis of covariance (ANCOVA) using summed pretest scores as covariates, dummy coding for treatment condition as the independent variable, and summed posttest scores as the dependent variable did not yield a significant difference ($F = 0.08$) between treatment and control conditions.

Discussion

In this paper, we have described the findings from a quasi-experimental study comparing changes in student belief about science and learning between an e-textile unit and a more traditional circuitry unit with eighth grade students. Significant differences favoring the e-textile condition were found on survey items regarding students' perceptions of family, peer, and teacher support for their engagement in science. These increases spanned perceptions of support both for science in the school context and for the pursuit of STEM-related careers. In the context of concerns over recruitment of students into the scientific workforce, this finding is especially noteworthy.

Table 4 Paired *t* test gains by assessment item within treatment and control conditions (two-tailed)

	Pretest mean	SD	Posttest mean	SD	*t* score	*p* value	Effect size (*r*)
Control							
Item 1	0.333	0.475	0.556	0.500	−3.090	0.003*	0.222
Item 2	0.797	0.306	0.888	0.271	−2.325	0.022*	0.156
Item 3	0.451	0.501	0.495	0.495	0.652	0.517	0.044
Item 4	0.936	0.247	0.962	0.194	−0.705	0.483	0.058
Item 5	0.760	0.430	0.810	0.395	−0.942	0.329	0.060
Treatment							
Item 1	0.348	0.480	0.507	0.504	−2.173	0.033*	0.159
Item 2	0.807	0.267	0.899	0.229	−2.949	0.004*	0.182
Item 3	0.440	0.500	0.440	0.500	0.000	1.000	0.000
Item 4	0.947	0.225	1.000	0.000	−2.041	0.045*	0.164
Item 5	0.760	0.493	0.840	0.369	−1.932	0.057	0.091

*$p < 0.05$

Such changes in STEM motivation and identity compatibility may be explained by several factors. Sheridan et al. (2014) suggest that one reason maker activities can effectively engage participants is the "tangible utility" (p. 528) of the products. For instance, instead of a more traditional classroom approach to circuitry where students might engage in decontextualized hands-on circuitry activities (as students did in the control unit in this study) "to teach *about* circuitry" (p. 528), e-textile projects provide a context in which knowledge can be *used* to make objects of more immediate relevance and value to students.

Further, based on observation and teacher report, students appeared to be motivated to share their projects with others. Kafai et al. (2014a) argue that aesthetics and personal choice play an important role in why e-textiles are successful in disrupting students' stereotypes and gendered views of digital technology. Because students can represent their personal interests in their e-textile projects, they may be more interested in sharing their projects with family and friends, which, in turn, provides a context for positive potential change in the ways those audiences perceived and identified them with science. Searle et al. (2014) similarly argue that as students shared their e-textile projects with friends, they were able to position themselves as more knowledgeable, demonstrating newfound expertise with working projects that drew positive attention around computing themes. In this study, both observations and teacher report suggest that students invested more out-of-school time in their projects as well, providing potentially more opportunities for them to identify as hard-working, interested, invested, and capable in science as they solved problems with their projects.

We see these qualities—tangibility, aesthetic, and shareability—as potential reasons why students working with e-textiles may have developed stronger interest in science related to important social relationships. They designed products that were physical and tangible, useful (as fashion), and easily sharable to audiences in and outside of the classroom. Future studies may be able to investigate explanations for students' changed perceptions in greater depth.

Although the current study did not demonstrate statistically significant advantages to the e-textile curriculum over the traditional unit, examination of the results offers encouragement for future work related to the use of e-textiles in classroom environments. Significant gains at the item level were more common in the treatment condition than the control, which suggests that larger sample sizes and more items covering a wider range of relevant content beyond simple, series, and parallel circuits and basic knowledge of electricity (e.g., resistance, short circuits) could demonstrate stronger advantages over traditional instruction. Further, the absence of significant differences in achievement between conditions are encouraging, because they demonstrate no loss in traditional assessment performance from participating in e-textiles as an experimental curriculum while realizing notable benefits related to interest and motivation. More nuanced assessments might have detected other relevant changes in student knowledge (e.g., computational circuits, the role of a common ground, or the polarity of LEDs). Further, these multiple-choice questions do little to capture students' learning of design-based principles such as problem solving and debugging. While these additional concepts have been well documented in e-textiles through ethnographic work (Kafai et al. 2014), customized assessments (Peppler and Glosson 2013), and tailored debugging problems (Fields et al. 2016), age-appropriate readily quantified assessments of such material have yet to be developed and validated. Further, clinical interviews may provide deeper insight into what and how students learn and how that learning differs between design projects and other types of instructional framing. It is likely that students' understandings of electricity flow, short circuits, and polarity would be particularly fruitful areas for deeper investigation (Kafai et al. 2014a, 2014b).

Conclusions

In this study, we present findings from the first controlled, comparative study of e-textiles and traditional electronic curricula in classroom science. Results suggest that e-textiles may support social connections with teacher, family, and friends that are particularly productive areas for developing students' interest in science. These findings converge with those of qualitative studies that have described increased engagement with underserved populations, including urban youth (Searle and Kafai 2015a, 2015b) and American Indian youth (Kafai et al. 2014). While we have provided quantitative trends showing potential for e-textiles in science classes, much more work needs to be done to investigate how and why e-textiles or related maker projects can help open up science to underrepresented students.

Because interest is an important influence on long-term cognitive and motivational outcomes for students (Hidi 1990), future research more clearly elucidating the causal mechanisms of student, peer, and familial changes are especially important. While the nature of data described here is associative in nature and was collected from a limited sample, we hope that future studies will pursue this work across other science classes and schools. Quasi-experimental designs accompanied by qualitative ethnographic inquiry may also provide information about how e-textiles and similar types of maker projects can create links for positive interest development in and beyond the classroom context.

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